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Design and Testing of Thin Walled Tube for Automotive Crush Can Application

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Abstract: Thin walled tubes are used for various applications across the industries. Application of thin walled tube for automotive crush can as an energy absorber is covered in this study. Automotive vehicles play a significant role in modern transportation. The deaths and injuries caused by car accidents have become a major concern for society. Engineers and scientists have been working tirelessly in recent years to improve overall vehicle safety. Crumple zones have been introduced to reduce the impact on and structures and travelers during a collision. To improve crashworthiness and energy absorption capabilities, more emphasis has been placed on the development of new designs of energy absorption devices such as crush cans and bumper beams. The crash analysis simulation and results can be used to evaluate the crashworthiness of the current design as well as to investigate ways to improve it. This type of simulation is an essential part of the design process and can eliminate the need for costly destructive testing. In this study, a FE model of thin walled tube as a crush can is proposed for axial compressive load and experimentally validated.

***KeyWords*:** Crashworthiness, Thin-walled tube, Automotive Crush can

I. INTRODUCTION

In today's world, the transportation system is extremely important. The primary mode of transportation used by people to travel between locations is the road. Concerns about making cars safer for occupants and cutting the cost of fixing vehicle structures are growing in the automotive industry[11]. The United States' introduction of the Highway Safety Act in the second half of the 20th century led to the creation of standards for vehicle manufacturers in a number of areas related to passenger safety. These safety regulations later became known as the Federal Motor Vehicle Safety Standards (FMVSS) in the USA, and soon after that, other nations began enforcing comparable standards and laws as fit for their respective regions. [12]. One of the frequently occurring events on Indian roads is a low speed rear impact. Vehicle commute speeds drastically decreased as passenger and commercial vehicle density on the road increased, and accidents became more frequent as a result. [2]. According to the Indonesian Statistics Bureau, the number of accidents has increased by more than 90% between 2000 and 2013. Due to this, increased demand has been encouraged to guarantee higher standards of vehicle safety. It has prompted ongoing research into creating effective energy absorbers to dissipate energy during an accident while safeguarding the car's occupant [10].

The designs of contemporary vehicles are typically more lightweight and crashworthy than those of earlier models, allowing the vehicles to simultaneously meet safety standards and cost-saving requirements for material usage and fuel efficiency. [8]. Various regulatory and assessment organizations are working to increase the car's passive and active safety, protecting the occupants during collisions and afterward. [4]. 30–40% of the total car weight is made up of the body-in-white (BIW) weight. Therefore, using optimally weighted elements in the car body will be crucial [6]. The chassis components known as front rail columns are responsible for absorbing about 40% of the kinetic energy generated when a car crashes. Due to the delay in initial folding and persistent rigidity over a brief period of time, if these columns are too rigid, this can result in significant negative accelerations and the possibility of the occupants colliding with the windshield of the vehicle [7]. Automobiles use thin-walled shell structures in a variety of ways to create these energy-absorbing parts [1]. In applications requiring high performance under impact loadings, thin-walled tubular structures are preferred. Thin-walled tubular components are used in automobiles to absorb impact energy in the event of a collision [14]. According to statistics, frontal collisions between vehicles cause the majority of traffic accidents, and the bumper system is crucial to the passive safety of the vehicle in these collisions. In order to lessen damage to the car and passenger casualties, it deforms to absorb the energy of the low-speed impact. The crash box, which is installed between the bumper beam and the frame stringer, is a key energy-absorbing element of the bumper system. In order to minimize collision damage to the front of the car's body and ensure the safety of the occupants, it can absorb as much of the beam's energy as possible[13].

Crash energy-absorbing member structures refer to a variety of parts in automobiles. Every crashworthiness study puts the most emphasis on the energy-absorbing components, like the bumper and crash box. Over the past few decades, thin-walled structures have been widely utilized as energy absorbers in the automotive industry, and their crashworthiness has been thoroughly investigated using theoretical, experimental, and numerical techniques [5]. A thin-walled structure made of metal or composite material that is fixed or mounted at the front of the vehicle is referred to as a crash box that is installed in a vehicle. In the event of a collision, the structure acts as a vehicle's energy-absorbing member. This crash box structure is anticipated to be able to absorb kinetic energy in a frontal crash, maintain the vehicle's deceleration within a safe range, and reduce the risk of injury to the vehicle's occupants during a collision as a passive safety system in a vehicle [3]. A decrease in mass translates into an increase in mileage for new energy vehicles. Therefore, academics and manufacturers have given much thought to how to strike a balance between an automobile's crashworthiness and its lightweight. To meet the dual demand, thin-walled structures can act as an ideal energy absorber [15].

The results of this study are validated through experimental testing on a rectangular tube with thin walls and a correlation study with a FE model. In order to understand the SEA difference between these designs, various thin walled structures including square, circular, hexagonal, and octagonal shapes are studied and their performance is compared to rectangular design. Though the dimensions, materials, and thickness were different from those used in other researchers' studies of a similar nature, S.B. Kim discovered that octagonal shapes SEA performed better than those of rectangular and hexagonal sections[9]. Studies by Mehmet A. Guler demonstrate that conical thin walled tubes SEA perform better than square and hexagonal designs. Adding some geometrical features, such as creating blanks on side walls and corrugations along axial directions, also results in a performance difference [11].

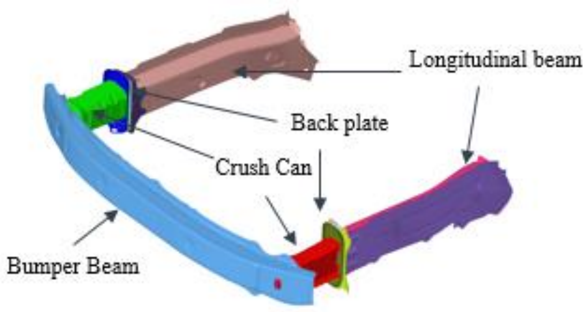

Figure 1. Crash management system (crush can) between main rails and bumper beam [6].

As shown in figure 1, Crash management systems are installed on the front and rear of an automobile. The bumper beam, crush can, base plates, and rails make up this system. We are limiting the subject of this study to crush can design. The four loading scenarios that are typically present in auto accidents are axial loading, oblique loading, lateral loading, and bending loading. The crash box structure and the axial and oblique loading conditions are interconnected [3]. As shown in figure 2. Axial loading of crush can is considered in this study. Here any object is hitting the crush box in axial direction and make crush can to deform. Crush can absorbs energy while deforming and avoid further damages by minimizing load transfer to occupant cabin. This not only saves further structure of vehicle from severe damage but also helps in minimizing injuries to occupants. In figure 2 we can see crush can is placed between two plates which are very stiff non deformable rigid pates. In that bottom plate is support plate, which is stationary, not moving. Where as top plate is impactor, which pushes crush can down towards support plate.

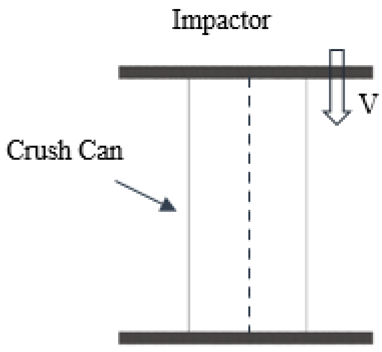

Figure 2. Axial loading of crush can [3].

III. PROBLEM STATEMENT

It is observed that lot of research has been carried out for finding best energy absorbing structure for crush can application. The present study focus on design of thin walled tube as crush can numerically and experimentally then validate it by correlating results.

IV. OBJECTIVES

i. To propose the Finite element model for the crush can and validate by performing experimental tests.

VI. MATERIAL

We identified the general range for crush can dimensions based on a review of the literature. For this study, we chose the closest available dimension, which is 2.5 mm thick and has a cross-sectional area of 93 mm X 50 mm and length of 215 mm, as shown in figure 3. A literature review is used to determine the final grade for the material. Our choice of steel has a UTS of close to 590MPa.Tensile properties of steel are characterized by performing tensile test by following ASTM E8 Standard in UTM machine as shown in figure 4.

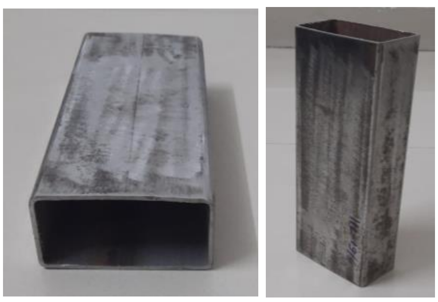

Figure 3. Thin walled tube selected as crush can for experimentation

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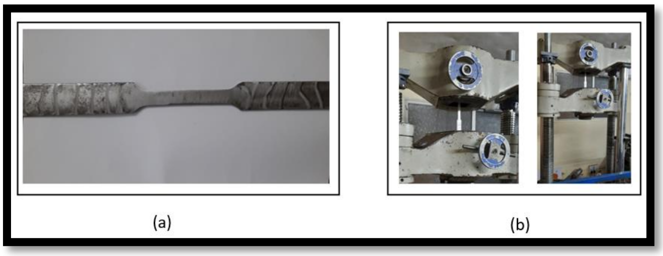

Figure 4. (a) Tensile test specimen, (b) Tensile test setup in UTM

VII. EXPERIMENTAL VALIDATION

Conducting compressive test experimentally on selected crush can on UTM machine. Load vs displacement values are noted down. FE model of crush can is prepared and CAE simulation is done for axial compressive load case. CAE data is correlated to experimental data. Experimental test and CAE simulation requirement are taken from literature review.

a) Experimental Setup

Compressive test will be done on UTM. Axial load case is considered for CAE simulation. Figure 5 shows setup condition for both experiment as well as CAE simulation.

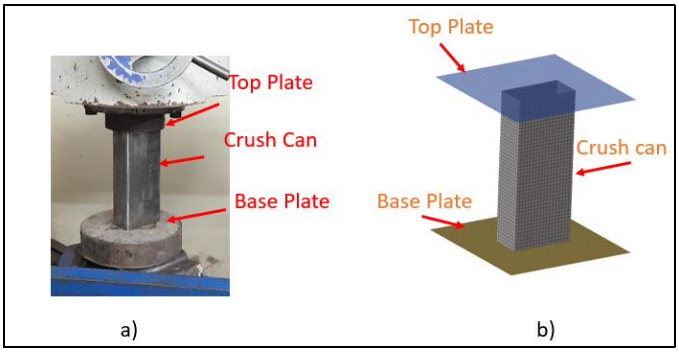

Figure 5. a) Axial load experimental setup, b) Axial load CAE Setup

Length of the crush can noted down before test and after test. Load is applied on crush can till the material stack up is done. Force vs displacement graph provided by test lab. Displacement shown in graph should be close enough to difference between length of crush can after test to before test. Initially load curve will rise sharply with less displacement in FD graph as the crush can is loaded up. As soon as crush can start to crush, load value decreases, and considerable displacement will take place. This process continues, peaks and valleys can be seen on FD curve. Similarly plastic deformation of crush can happen, and folding pattern can be seen visually. FD curve is plotted till material stack up takes place. After that crush can is removed from UTM and measured final length of crushed crush can.

b) CAE Setup

Hypermesh preprocessor is used to prepare finite element model of thin walled tube as crush can. 5mm average element size with quad 4 shell elements are used in model preparation. LS Dyna solver code is used to run the CAE Simulation. Quasi static axial crush simulation is done. Crush can model is placed on rigid fixed plate and connected through node to surface contact. Rigid moving plate, which is allowed only to translate in axially is put on top of crush can, and it is pushed axially through prescribed boundary motion. MAT24 is applied to crush can and MAT20 is applied to impactor and support plates.

VIII. RESULTS AND DISCUSSION

Results from experimental test are correlated with simulation results. In figure 6, Force – displacement (FD) curves for two experimental tests are plotted along with simulation FD curve. In figure 6, we can see initial peak load of experimental test are very close to each other as well as with simulation peak load. Once the curves drop from 1st peak till the material stack up we can see average load. In figure 6, we can see average load of experimental test are also in good correlation with simulation average load. Force values and trend of FD curves shows good correlation between experimental data and CAE data. As the UTM starts applying axial compressive load on crush can, Force value rises in the graph. Once side wall of crush can starts to buckle, the force value drops in the graph. This process continues, peaks and valleys seen in graph in accordance with multiple material folds on crush can side walls.

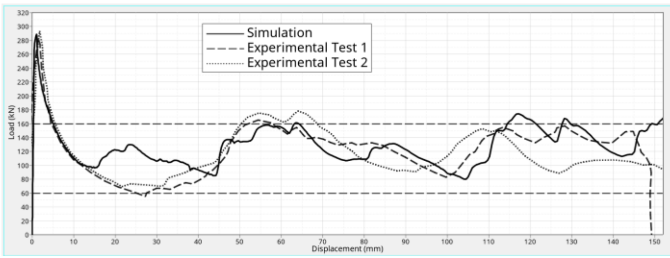

Figure 6. Force-Displacement curve correlation

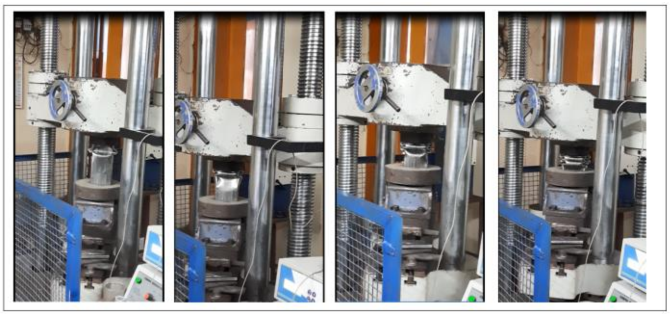

Figure 7. Deformation mode of crush can

In Figure 7 we can see deformation mode of crush can in experimental test. We can notice deformation modes are progressive, material is folding in a very systematic way and at the end all materials get crushed and stack up. This is what really makes thin walled tubes suitable for crush application. Progressive deformations keeps on absorbing energy by maintaining particular load level. That particular load level is nothing but average load we are seeing in FD curve.

IX. CONCLUSIONS

FE model of thin walled tube for automotive crush can application is proposed for axial compressive load and validated by experimental test. FD curve shows good correlation between simulation and experimental test. Crush modes shows very progressive deformation in experimental test, which is highly desirable for automotive crush can application. This kind of correlation validates FE model setup, boundary conditions with physical model and can be used for further optimization of design.

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